

## Revisiting the outstanding flooding episode of November 1967 in the greater metropolitan Lisbon area

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**Abstract:** The deadliest storm affecting Portugal since, at least, the early 19th century, took place on the 25 and 26 November 1967 causing more than 500 fatalities. Here we provide a comprehensive multi-disciplinary assessment of this episode, including the main socio-economic impacts, particularly the numbers and location of victims (dead, injured, homeless and evacuated). Based on the sub-daily time series of a representative station, and its Intensity-Duration-Frequency curves, we have found that the exceptionality of this rainfall event is particularly linked to rainfall intensities ranging in duration from 4 to 9 hours compatible with return periods of 100-years or more. This range of time scale is similar to the estimated concentration time values of the hydrographic basins affected by the flash flood event. Most victims were sleeping or were caught by surprise at home in the small river catchments within the greater metropolitan Lisbon area. The majority of people who died or who were severely affected by the flood lived in degraded housing conditions often raised in a clandestine way, occupying flood plains near the stream beds. This level of destruction observed at the time is in stark contrast to what was observed in subsequent episodes of similar amplitude. In particular, since 1967 the Lisbon area, was struck by two comparable intense precipitation events in 1983 and 2008 but generating considerably fewer deaths and evacuated people.

**Keywords:** Extreme precipitation, Lisbon, Flash Floods, Natural Hazard, Atlantic storms

### 1. Introduction

Flash floods induced by extreme precipitation events are one of the most life-threatening hazards in western Iberia (Fragoso et al., 2010; Liberato et al., 2012; Trigo et al., 2014). This fact is in line with many other regions of the world, where flooding events represent one of the most frequent and costly natural hazards. Recently, some of us have developed a long-term database of hydrological events for Portugal, since 1865, within the scope of project DISASTER. The DISASTER database comprises 1621 flood cases for the period 1865-2010 that were responsible for a combined death toll of 1012 people and more than 40,000 homeless people (Zêzere et al., 2014). More than half of these fatalities took place in a single event in November 1967.

On 25-26 November 1967 heavy precipitation occurred with unprecedented intensity around the Lisbon metropolitan area, soon followed by flash flooding and a burst of landslides in the peripheries of Lisbon (Zêzere et al., 2005) causing significant socio-economic impacts. Without a proper warning system installed, according to Ramos and Reis (2002) 700 people died as a consequence of the floods on the heavily populated metropolitan area of Lisbon. Additionally, almost 900 people lost their homes and several road and train communications were disrupted. The official number of dead people was 495, but at that time the media were strictly controlled by the government and the catastrophe numbers could have been kept lower for political reasons. According to the DISASTER database the death toll reached 522 casualties (Zêzere et al., 2014), while unofficial assessments indicate more than 700 deaths.

Overall, this was the deadliest storm in Portugal during the 20th century and the deadliest natural hazard since the 1755 Lisbon earthquake, not accounting heat waves. Nevertheless, to the best of our knowledge this extreme hydro-meteorological episode was never studied in detail. We should recognize three additional factors that have contributed for the inexistence of an in-depth analysis of such extreme event both in the Portuguese and international literature until now: 1) the absence of a dynamic meteorological and hydrological research community, 2) the unavailability of a high resolution precipitation dataset covering the entire territory and 3) the inexistence of a list of places with the affected people and socio-economic impacts. These last two limitations were overcome to a large extent in recent years. Firstly, a comprehensive list of people affected (fatalities, injured, displaced, evacuated and disappeared) has been obtained through the DISASTER database (Zêzere et al., 2014). Secondly, a new high density daily precipitation gridded dataset developed by the Portuguese and Spanish meteorological offices is particularly appropriate for this study and was already used to rank extreme precipitation events in Iberia (Ramos et al., 2014).

The aim of this work is to evaluate and characterise the impacts of the November 1967 floods, namely to determine the spatial distribution of precipitation anomalies using a recent high resolution dataset for Portugal and also to characterize the impacts and spatial distribution of flash floods in Lisbon and 14 surrounding municipalities around the Lisbon area. This study corresponds to a short version of the recent publication covering a comprehensive analysis of this extreme event (Trigo et al., 2015).

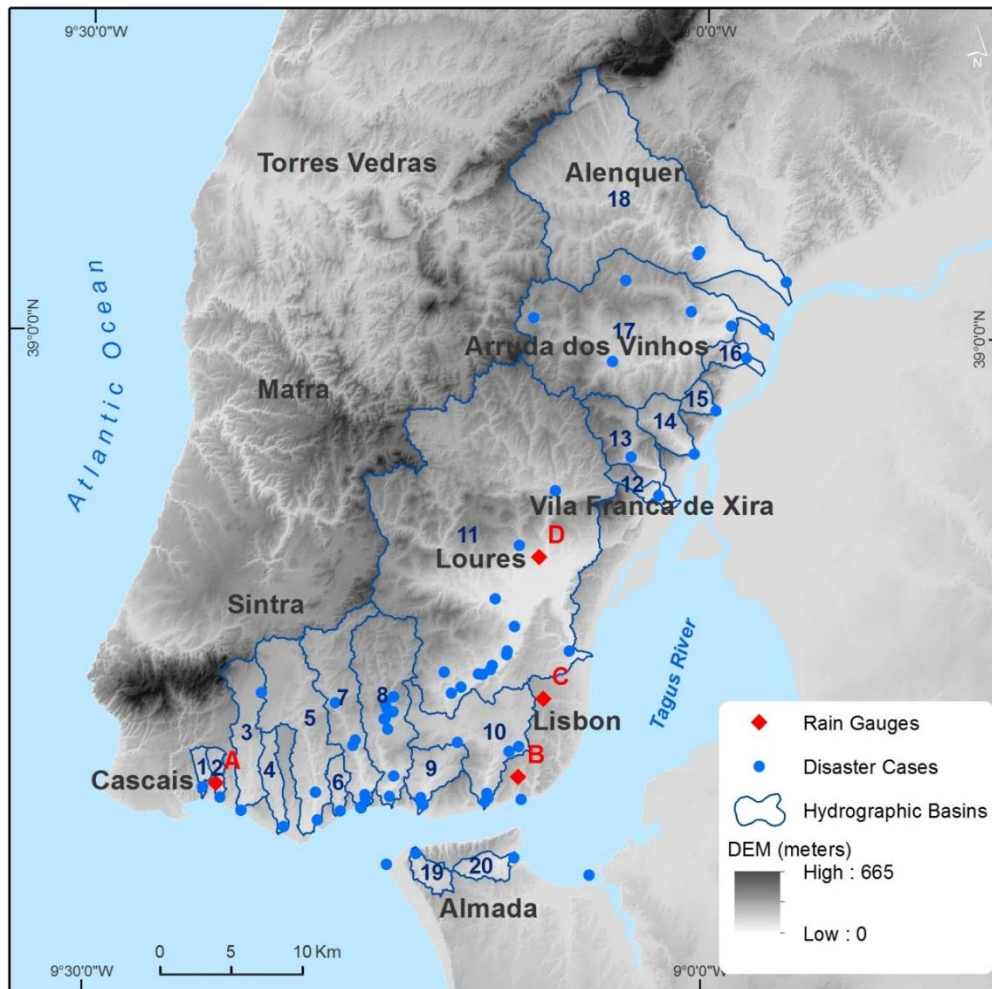
## 2. Datasets and Methodology

### 2.1 Historical sources

The main historical data source used here corresponds to the recent dataset of flooding and landslide events that took place in Portugal since 1865 and aggregated within the scope of DISASTER project (Zêzere et al., 2014). The DISASTER database provides detailed information on each individual hydro-meteorological case including; 1) its location, 2) type (flood or landslide), 3) occurrence date, 4) date of the corresponding newspaper publication and 5) involved rescue entities. Additionally, this database often makes available further contextual information for each event and the nearby affected town/region, including the number of i) human fatalities, ii) people injured, iii) people disappeared, iv) homeless people, v) people evacuated as well as the overall socio-economic costs. The DISASTER database was used to extract the DISASTER cases of the November 1967 event. A DISASTER case is a unique hydro-geomorphologic occurrence - flood or landslide -, which independently of the number of affected people, caused casualties, injured or missing, evacuated or homeless people, and is related to a unique space location (Zêzere et al., 2014).

### 2.2 Precipitation datasets

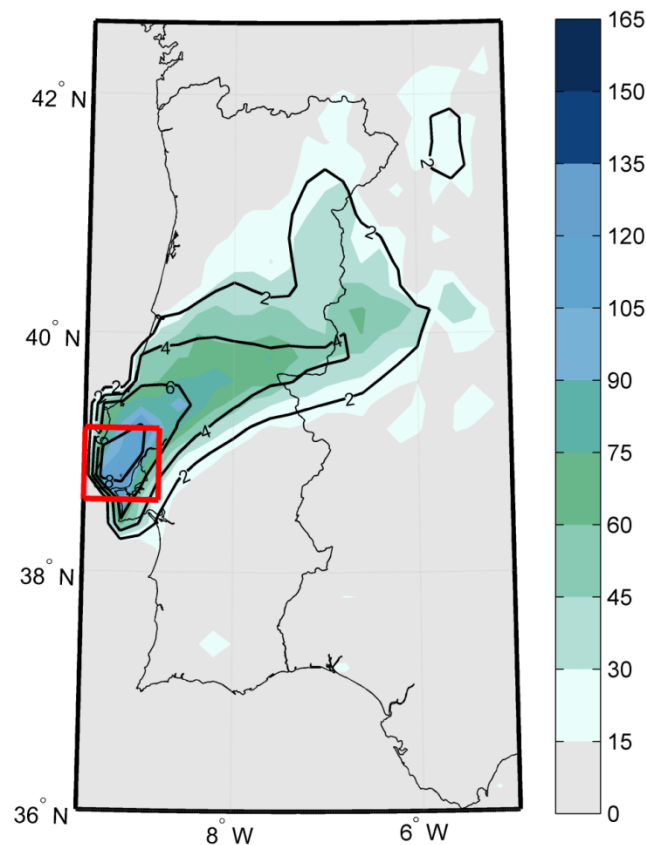
To characterize the distribution and spatial extent of this extreme event we have used 'IB02' the most comprehensive database of daily precipitation available for mainland Portugal and Spain (Ramos et al., 2014). The 'IB02' database spans from 1950 to 2008, with a spatial resolution of 0.2° latitude/longitude grid. This database is based on a dense network of rain gauges, combining with a total of more than eight hundred stations over Portugal, and two thousand over Spain all quality-controlled and homogenized. Additionally we used daily and hourly precipitation data registered in four rain gauges: S. Julião do Tojal, Monte Estoril, Lisbon/Airport and Lisbon/Geophysical Institute from the National Weather Service (see location in Figure 1).



**Figure 1** – Location of the drainage basins affected by the November 1967 flood (blue numbers), the Disaster cases (blue dots) and the rain gauges (red). Hydrographic Basins (blue): 1 – Monte Estoril; 2 - São João do Estoril; 3 - Caparide; 4 - Marianas; 5 - Laje; 6 - Porto Salvo; 7 - Barcarena; 8 - Jamor; 9 - Algés; 10 - Alcântara; 11 - Trancão; 12 - Crós Cós; 13 - Silveira; 14 - Santo António; 15 - Santa Sofia; 16 - Castanheira; 17 - Grande da Pipa; 18 - Alenquer; 19 - Caneira; 20 - Caramujo. Rain gauges (red): A – Monte Estoril; B – Lisbon, Geophysical Institute; C – Lisbon, Airport; D – São Julião do Tojal

### 3. Rainfall event and hydrologic context

The main cause for these catastrophic floods is related to the large amount of precipitation concentrated during a few hours on the night of 25 - 26 November. According to the IB02 database the pattern of intense precipitation (above 75 mm) is oriented with a SW-NE axis and crosses roughly the central region of Portugal (Figure 2). Moreover, it is possible to observe an area where the daily precipitation surpassed the 120 mm threshold located over the metropolitan region of Lisbon. In addition, this extreme value corresponds to an anomaly above 8 standard deviation from the long term climatology (1950-2008).

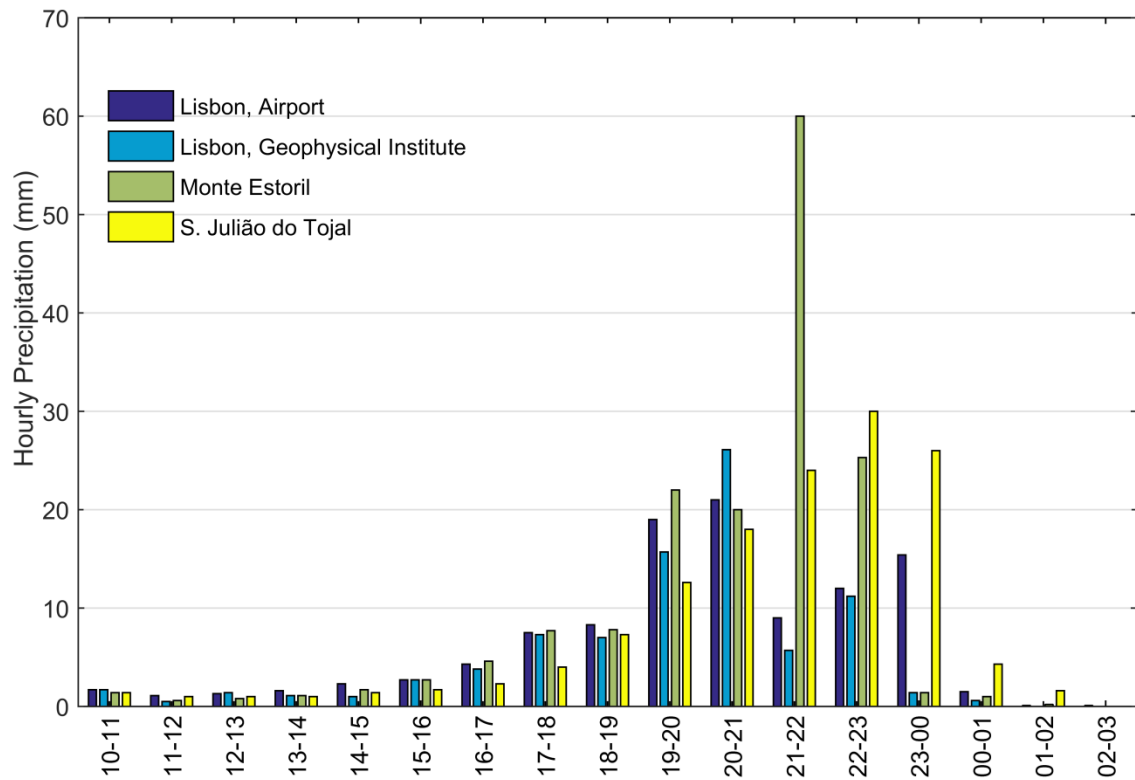


**Figure 2** – Daily accumulated precipitation (mm, shaded) and corresponding standard deviation anomalies (black contour) for the 25 November 1967. The standard deviation anomalies were smoothed with the neighbour grid points. The red box highlights the selected area over the Lisbon metropolitan where the mean precipitation over that area was computed

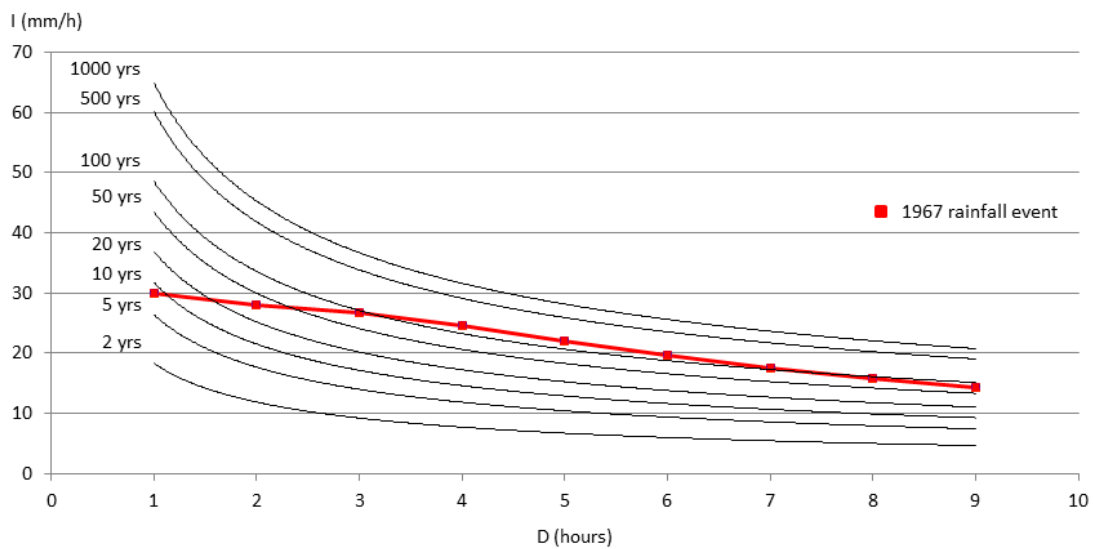
In order to put into context the November 1967 event, we have selected an area over the Lisbon metropolitan region (red square Figure 2) and for each day, the mean precipitation over that area was computed. Results show that the November 1967 event corresponds to the second most intense 24h average precipitation for that area between 1950 and 2008, with a mean precipitation of about 86mm. The most intense precipitation event within this period, over that same Lisbon region, corresponds to the case of November 1983 (mean precipitation of around 95mm) which was already mentioned in the introduction section and evaluated in detail in Liberato et al. (2012).

The 25-26 November 1967 flash flood event was triggered by an extreme rainfall event that reached 137mm in 24 hours, almost 1/5 of the mean annual rainfall at S. Julião do Tojal. 3 shows the hourly rainfall registered at four rain gauges in the Lisbon region, starting at 1000UTC on the 25 November and finishing at 0300UTC on the 26 November. The hourly data shows that most of the rainfall was concentrated in just five hours (between 1900UTC and midnight). Moreover, during these five hours 110.6 mm were registered in S. Julião do Tojal, which is equivalent to the monthly average rainfall of November (112.5 mm). In this station, a peak of precipitation 30mm/h was recorded between 2200UTC and 2300UTC, corresponding to a 10-year return period. However, the maximum hourly rainfall (60 mm/h) was registered in a different station, namely Monte Estoril between 2100UTC and 2200UTC (Figure 3). Monte Estoril is located in the western part of the study area and was firstly affected by the precipitation.

The sub-daily precipitation time series at S. Julião do Tojal, and the corresponding Intensity-Duration-Frequency (IDF) curves (Figure 4) show that the exceptionality of this rainfall event is particularly linked to rainfall intensities ranging in duration from 4 to 9 hours compatible with return periods of 100-years or more.



**Figure 3** – Hourly precipitation registered at four rain gauges located over the Lisbon region (see Figure 1 for location) starting at 10UTC of 25 November and ending at 03UTC of 26 November 1967. Source: Portuguese National Weather Service (Instituto Português do Mar e da Atmosfera)

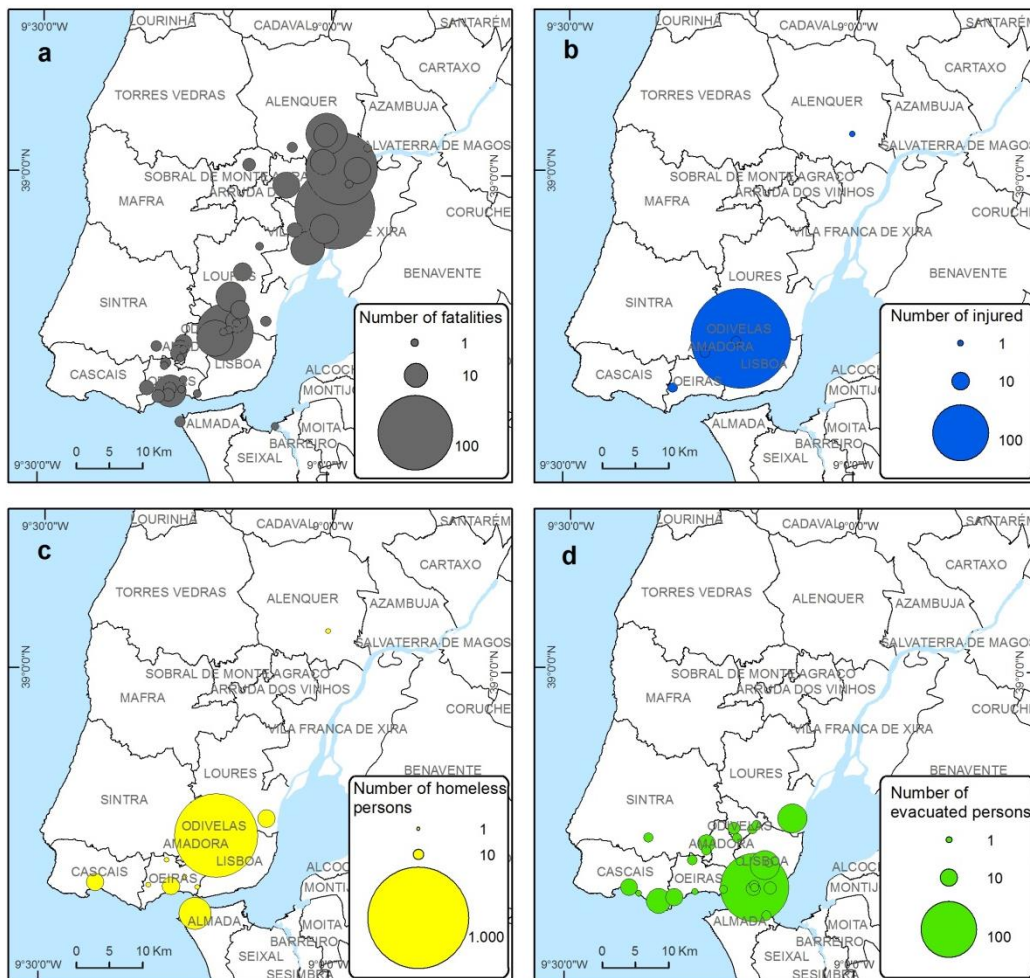


**Figure 4** – Rainfall Intensity-Duration-Frequency (IDF) curves for return periods ranging from 2 to 1000 years at S. Julião do Tojal. The 25-26 November 1967 rainfall event is represented in red



#### 4. Exposure and socio-economic impacts

According to the DISASTER database, 2045 people were directly affected by the November 1967 flash floods and their location and number are shown in Figure 5. The number of confirmed fatalities is 522. In addition, 330 injured, 885 homeless and 307 evacuated people were reported. Of the 121 years with flood events with human damage, registered in Portugal between 1865 and 2010, the November 1967 flash flood was the deadliest and the one that generated more fatalities. The numbers are impressive: the November 1967 flash flood was responsible for 52% of total casualties and 69% of the total number of injured caused by floods in Portugal from 1865 to 2010.



**Figure 5** – Location and number of (a) fatalities, (b) injured, (c) homeless persons and (d) evacuated persons caused by the November 1967 flash flood. Results were aggregated per municipalities. Source: DISASTER database (Zêzere et al., 2014)

Reports of survivors and firemen on newspapers indicate that the majority of deaths have occurred during the peak of the flood between 2230UTC and 0230UTC, depending on the river basins. Therefore, many of the victims were sleeping or were caught by surprise at home. People who died or who were severely affected by the flood (injured, homeless or evacuated) lived in flood prone zones, often in degraded housing conditions (slums or pre-fabricated storey houses). At that time, a huge exodus from the rural areas towards the coastal cities was registered (in particular to the Lisbon metropolitan area), due to socio-economic conditions of extreme poverty and high birth rates in the inner country. These people built many

of their houses or shacks in a clandestine way, occupying flood plains and stream banks. The names and birthplaces of dead victims that were published by the newspapers the days after the event indicate that most of the victims were coming from the rural areas of the country (mostly North and Alentejo).

Flash floods also dragged a large amount of debris (wood, tiles, and metallic structures from the shacks destruction, vehicles, stones and mud) that raised the destruction capacity of the flood. According to newspapers, two important bridges were destroyed. One located in Odivelas municipality over the Costa stream that cut the road connection between Lisbon and Odivelas to Loures. Another bridge was destroyed over the Trancão River cutting the road connection between Loures and Bucelas. In these cases, flood effects were more devastating and emergency operations were even more difficult due to the increasing of travel times.

## 5. Conclusions

On the night of 25 November 1967 and early morning hours of the following day, the Lisbon area suffered the deadliest natural hazard since the ill-famed 1755 earthquake. Nevertheless, several factors, including lack of appropriate datasets (meteorological, hydrological and human impacts), have hampered an in depth analysis of this extreme event.

Based on the sub-daily time series of a representative station, and its IDF curves, we have found that the exceptionality of this rainfall event is particularly linked to rainfall intensities ranging in duration from 4 to 9 hours. For this range of temporal scales, the rainfall intensity (mm/h) is characterised by return period values close to or clearly above the 100-year IDF curve. This conclusion is particularly important because the estimated concentration time values of the hydrographic basins affected by the flash flood event are of a similar duration, less than 6 hours in 70% of the hydrographic basins and the remaining 30% present concentration times ranging from 6 hours to 9h30m. From a meteorological perspective this episode was characterized by strong convection at the regional scale, fuelled by high availability of moisture over the study area associated with a low pressure system near Lisbon that also favour the convective instability (Trigo et al., 2015).

Most victims were registered in the small river catchments within the main Lisbon metropolitan area, including more than 500 fatalities, and many more injured, displaced, evacuated and disappeared. Considering the time of the flash floods in the different stream catchments most victims were sleeping and were caught at home. The majority of people who died or who were severely affected by the flood lived in degraded illegal houses, often occupying flood plains and stream banks. This socio-economic context is important to appreciate the level of destruction observed at the time, in contrast to comparable episodes that took place afterwards. Interestingly, since 1967 the larger metropolitan region of Lisbon was hit by other intense precipitation events with comparable amounts of rainfall, namely in 1983 (Liberato et al., 2012) and 2008 (Fragoso et al., 2010) but generating considerably fewer deaths and evacuated people as quantified in the DISASTER database (Zêzere et al., 2014). This significant change in the amplitude of the human havoc might reflect the improvement of construction codes in flood prone areas after 1967.

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